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DYNAMIC DUAL CONTROLLER STRATEGY FOR GRID TIED POWER CONVERSION SYSTEM

RAMAGIRI MAHESH[1] & D.S.G KRISHNA[2]

[1]M.Tech Scholar, EEE Dept, VNR VJIET, Telangana, India

[2]Assistant Professor, EEE Dept, VNR VJIET, Telangana, India

ABSTRACT

This paper proposes a dynamic frequency and power flow control strategy for power conversion system to support grid during dynamic changes in the energy demand. Proposed control scheme contains dynamic frequency controller along with grid supporting controller. Dynamic frequency controller is a limited time controller, which limits the frequency droop for sudden changes in the load demand. Grid supporting controller is a full time controller which continuously controls power flow from DG to grid based on frequency and voltage droop. Proposed system is simulated in Matlab/Simulink and results are presented.

KEYWORDS: Distribution Generation (DG), VSI, Droop, Dynamic Frequency Controller (DFC), Grid Supporting controller (GSC)

INTRODUCTION

Now a days, the demand of electricity is increasing, so to meet the demand renewable energy like solar, wind energy etc., come in to picture and solar energy is abundant in nature. DG integrated to the grid is happening in view of energy demand. Whenever significant DG is available sudden changes in the energy demand can be met. But it is also equally important, how fast the DG control system acts . As the sudden and significant changes in the energies demand will cause huge frequency and voltage droop, which may lead to isolation of control area in which DG is present. Present paper proposes control scheme to limit the frequency and voltage droop and continuously control the power flow to grid from DG.

DG generates DC-Power is boosted up by Multilevel Interleaved DC-DC boost converter [1] which is further converted to AC-Power by voltage source inverter(VSI) .VSI interface DG and main grid by converting DC-power into AC-Power. VSI switches are controlled by the mathematical model of space vector pulse width modulation in [2]. VSI not only converts the power but also control the power flow to the load. VSI is controlled based on the droop of frequency and voltage magnitude at the DG output which indirectly control the active power and reactive power. Active power depends on the phase angle. If frequency is changed that indirectly affects the flow of active power. Change in voltage magnitude will affects the flow of reactive power to grid.

In this paper a dynamic frequency controller is designed[5] which works based on the load dynamics, from which change in phase angle is determined and incorporated in the PWM, which indirectly control the flow of active power. Similarly a controller is designed to obtain change in magnitude, that error is incorporated to PWM to control the reactive power flow[6].

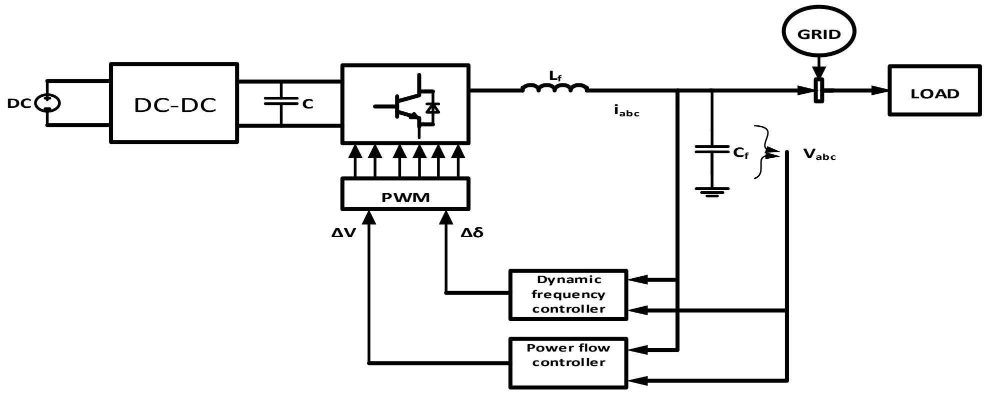

Figure 1: Overview of Grid Connected System

MULTILEVEL INTERLEAVED DC-DC BOOST CONVERTER.

Multilevel interleaved DC-DC boost converter will convert the input voltage based on duty ratio, which can be input from MPPT control of solar or wind generator. Interleaved boost converter is designed with two boost converter connected in parallel with a single capacitor at its output as shown in fig.2.

Operation of switches are controlled by the interleaved method, it is nothing but phase-shifted switching function. As two DC-DC boost converter are connected in parallel a phase shift of 180 degree is maintained in between two control signals that are provided to the switches [1].

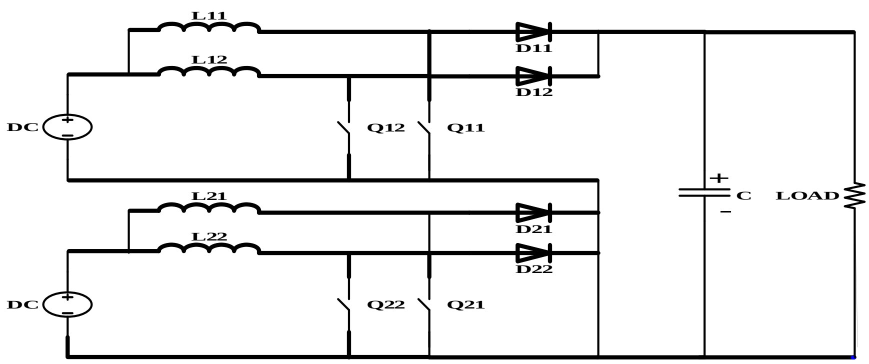

Figure 2: Multilevel Interleaved Boost DC-DC Boost Converter

OPERATION OF MULTILEVEL INTERLEAVED DC-DC BOOST CONVERTER.

In order to simplify the calculation it is assumed that the inductance value are taken equal for both the converters.i.e. $L_{11} = L_{12} = L_{21} = L_{22.}$

- From time $T_0 – T_1$,Q_{11} and Q_{21} are closed and Q_{12} , Q_{22} are opened. The current of the inductorsL_{11} ,L_{21} starts to risewhile L_{12} , L_{22} are dischargesthrough the capacitor.

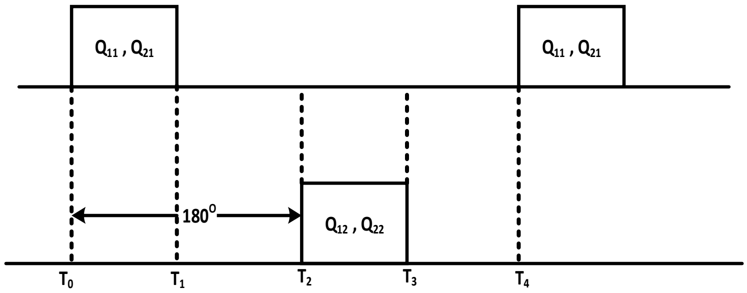

Figure 3: Timing Control Signals

- From time $T_1 – T_2$, Q_{11}, Q_{12}, Q_{21} are open ,all the inductorsdischargesthrough the capacitor.
- From time $T_2 – T_3$, $Q_{12}$and Q_{22} are closed and Q_{11} , Q_{21} are opened. The current of the inductorsL_{12} ,L_{22}starts to risewhile L_{11} , L_{21} are dischargesthroughcapacitor.
- From time $T_3 – T_4$ all the switches are opened and alreadychargedinductorsdischargedthrough the capacitor.[1]

STATIC CONVERTER

Power electronic converters are used in Distribution generation for power conversion and to control power flow inside the Distribution generation as well as within the main grid.

In this paper voltage source inverter is used to convert DC- Power to AC- Power and it plays major role in control of Active and reactive power.

Inverter can be controlled by space vector pulse width modulation.Mathematical model of space vector pulse witdth modulation is given.

Step1:- Read the sampled amplitudes of V_{AN} ,$V_{BN}$and V_{CN} for sampling interval.

Step2:- Determine the time equivalents of phase voltages i.e.,

τ_{as} , $\tau_{bs}$and τ_{cs}

$\tau_{as}= V_{AN} * \tau_s(n-1)/V_{dc.}$

$\tau_{bs}= V_{BN}* \tau_s(n-1)/V_{dc\,.}$

$\tau_{ca}= V_{CN}* \tau_s(n-1)/V_{dc.}$

Where ‘n’ is the number of levels.

Step3:- Determine $\tau_{max}$and τ_{min}which are maximum and minimum of τ_{as} , τ_{bs} , τ_{cs}respectively.

Step4:- $\tau_{avg}= -(\tau_{max}+ \tau_{min})/2$

Step5:- Determine τ^*_{as} , $\tau^*_{bs}$and τ^*_{cs}as

$\tau^*_{as} = \tau_{as}+ \tau_{avg.}$

$\tau^*_{bs}= \tau_{bs}+ \tau_{avg.}$

$\tau^*_{cs}= \tau_{cs}+ \tau_{avg.}$

Step6:-Compare $\tau^*_{as}, \tau^*_{bs}, \tau^*_{cs}$ with triangular signal to obtain pulses to the inverter switches.[2]

FILTER DESIGN

Inverter output voltage contains high frequency switching harmonics which are to be filtered before feeding the load. A typical second order low pass filter can be used to avoid harmonics of order of switching frequency or multiples of it. A second order filter gives better attenuation than first order at any given frequency. So, an LC filter is preferred over L filter[3].

Table 1 Properties of Filter

Filter	Order	Atten uation	Resonating Frequency
L	First	-20 dB/decade	----
LC	Second	-40 dB/decade	$\frac{1}{2\Pi\sqrt{LC}}$
LCL	Third	-60 dB/decade	$\frac{1}{2\Pi}\sqrt{\frac{L_1+L_2}{L_1L_2C}}$

The design procedure of LC filter is clearly explained in this paper.

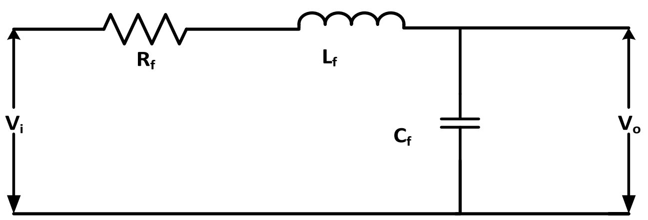

Figure 4: LC Filter

Transfer function of LC filter.

$$G(S) = \frac{V_o(s)}{V_i(s)} = \frac{1}{L_fC_fS^2 + R_fC_fS+1}$$

Comparing it with standard second order characteristic equation,

$$s^2+2\xi w_n s + w_n^2 = s^2 + \frac{R_f}{L_f} + \frac{1}{L_fC_f}$$

Resonating frequency $w_o = \frac{1}{\sqrt{L_fC_f}}$,

Resonant peak $Q = \frac{1}{R_f}\sqrt{\frac{L_f}{C_f}}$

Voltage drop in the filter is expressed as

$$V = L_f\frac{\Delta I}{\delta T_s} + (\Delta I)R_f$$

δ is the duty ratio. T_s is switching time period.

As per IEEE standards 519-1992, the allowable range of ripple is 15 - 20% of rated current.

Rated current of output/load,

$I = \frac{S}{V}$

Where S and V are apparent power and voltage rating of load respectively. Select resonating frequency f_o to be 1/10 of switching frequency f_s to get 40 dB attenuation

$20\log(\frac{\omega_s}{\omega_o})^2.=40$

Choose ξ in the limits $0 < \xi < 1$ to get stable response.[3]

DYNAMIC FREQUENCY CONTROLLER(DFC) AND GRID SUPPORTING CONTROLLER.

- Function of DFC ismainly to accelerate the power flow from DG to grid. It fills up the energy gap betweendemand and supplyquickly. Thengridsupportingcontrollercomesintopicture. So DFC isaprimarycontrollerwhereasGridsupportingcontrolleris a secondarycontroller.
- DFC ismodeledassuminggrid as a control area.
- DFC controlleragainconsists of frequencydroop compensation loop and steady state erroreliminatorwith$K_s$gain.
- Control area isconsidered as a 4[th]order system consideringgenerationdelay at power station as T_T ,T_{sg} and $T_p$isconsidered as delay due to system inertia as shown in fig. Typical standard values of time delays and gains were chosen to implementcontroller[5] as shown in table II.

Table 2: Parameter Values for Dynamic Frequency Controller

Parameter	Value	Parameter	Value
K_{sg}	1	T_{sg}	0.4
K_T	1	T_T	0.5
K_P	100	T_P	20
K_i	0.09		

From fig.6.where ΔP_dIs the demanded power

$\Delta P_r$is the power obtained at the distribution generation

Where $\Delta P(s) = \Delta P_r(s)-\Delta P_d(s)$

$$\Delta F(s) = \left(\Delta F(s)\left(\frac{-0.09}{s} - \frac{1}{3}\right)\left(\frac{1}{(1+0.4s)(1+0.5s)}\right) - \frac{\Delta P(s)}{s}\right) * \frac{100}{20s+1}$$

$$\frac{\Delta F(s)}{\Delta P(s)} = \frac{-60s^2 - 270s - 300}{(s+0.30s)(s+3.72)((s+0.26)^2 + (1.38)^2)}$$

By partial fraction

$$\frac{\Delta \mathrm{F(s)}}{\Delta \mathrm{P(s)}} = \frac{A}{(s+0.30s)} + \frac{B}{(s+3.72)} + \frac{Cs+D}{(s^2+0.5s+1.972)}$$

On solving the above equation, the arbitrary constants are

A = -34.288 , B = 2.6569, C = 31.643, D = -44.28

$$\frac{\Delta \mathrm{F}(s)}{\Delta \mathrm{P}(s)} = \frac{-34.288}{(s+0.30s)} + \frac{2.657}{(s+3.72)} + \frac{31.6432(s+0.26)}{((s+0.26)^2+(1.38)^2)} - \frac{52.5064}{((s+0.26)^2+(1.38)^2)}$$

Apply inverse Laplace transform

$$\frac{\Delta \mathrm{F(t)}}{\Delta \mathrm{P(t)}} = 2.657e^{-3.72t} - 34.28e^{-0.305t} + 31.63e^{-0.26t}(\cos 1.38\mathrm{t}) - 37.639e^{-0.26t}(\sin 1.38t)$$

$$\Delta \mathrm{F(t)} = \Delta \mathrm{P(t)}\ [2.657e^{-3.72t} - 34.28e^{-0.305t} + 31.63e^{-0.26t}(\cos 1.38\mathrm{t}) - 37.639e^{-0.26t}(\sin 1.38t)\ ]$$

$$\Delta\delta = \int \Delta \mathrm{F(t)}$$

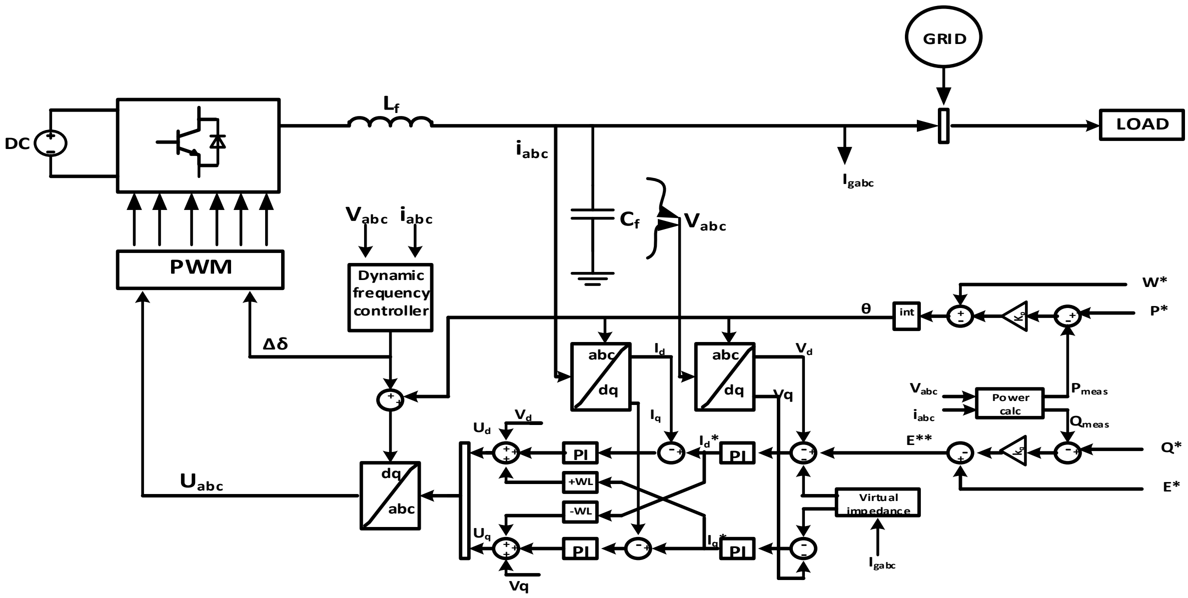

Figure 5: Control of Static Converter with Dynamic Frequency and Grid Supporting Controller

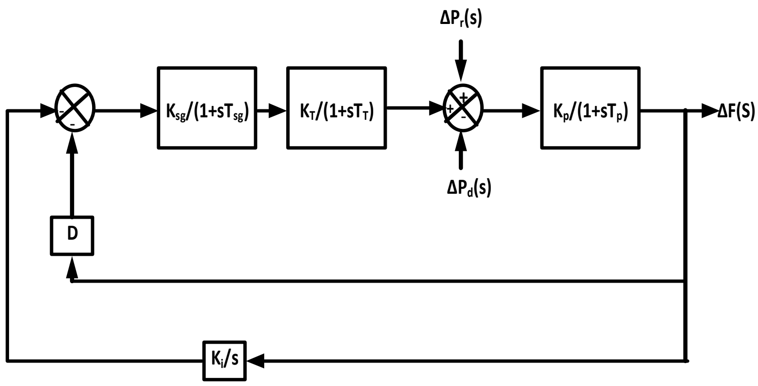

Figure 6: Dynamic Frequency Controller

Grid supporting controller is secondary controller to respond dynamic changes. Basic equation for active and reactive power control are given from[4].

$$P = \frac{E_d}{R^2+X^2} * [\, R(E_d - E_g\cos\delta) + XE_g\sin\delta] \quad (1)$$

$$Q = \frac{E_d}{R^2+X^2} * [\, X(E_d - E_g\cos\delta) - RE_g\sin\delta] \quad (2)$$

Where E_d is distribution generation voltage and $E_g$grid voltage.δ is the phase angle difference between the E_d andE_g. As phase angle difference is typically small we can assume sin(δ) = δ and cos(δ) =1. In overhead lines X>> R so we can neglect the R. Therefore the flow of real power is proportional to the phase angle difference and flow of reactive power is proportional to the voltage magnitude difference (E_d - E_g).The real power from each Distribution generation unit can be controlled by varying the Distribution generation output frequency and hence the phase angle. Reactive power can be regulated by changing the distribution generation output voltage magnitude, which makes a difference in the grid voltage and distribution generation voltage, that error used to overcome the reactive power. Dynamic frequency controller is designed based on load dynamic to compensate the required active power and voltage magnitude change controller is designed to overcome the need of reactive power.[4]

A controller is designed as in the fig.6. which takes the input as voltage, current, power, which gives output as change in magnitude. This change in magnitude is given to the PWM. To this controller dynamic frequency controller output is added which is additional further to the controller to react controller based on the dynamics of load.

SIMULATION RESULTS

- Active power transfer to gridwith change in loadisshown in fig.7. withoutcontroller. Evenwith change in load at 2.5sec the DG issupplying constant power throughoutitsoperation.

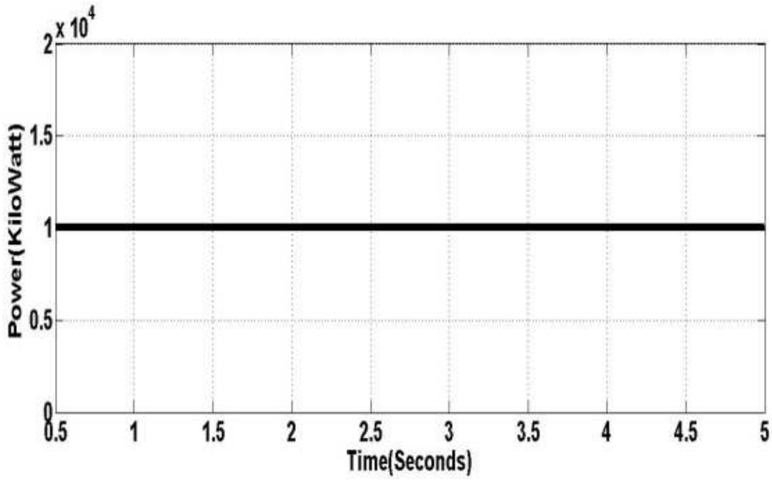

Figure 7: Without Controller, Load Change at 2.5sec

- Active power transfer to gridwith change in load at 2.5sec isshown in fig.8. withcontrollerwecan observe thereisaincrease in power flow.

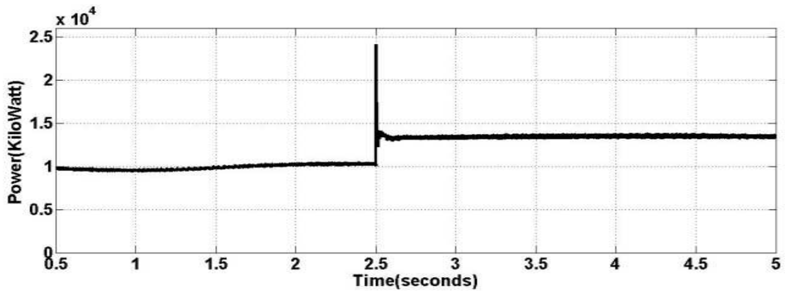

Figure 8: With Controller, Load Change at 2.5sec

- Dynamicfrequencycontroller output as shown in fig.9. and fig.10.

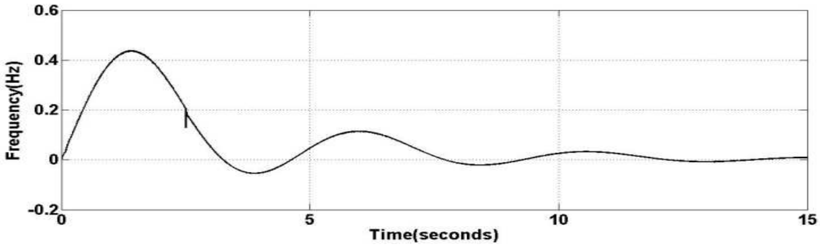

Figure 9: Output of Dynamic Frequency Controller

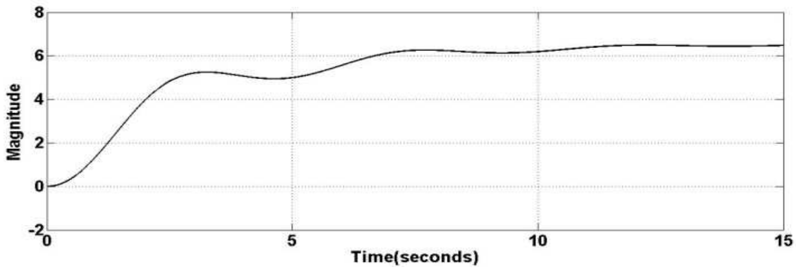

Figure 10: Integration of Output of Dynamic Frequency Controller to Obtain Change in Phase Angle

- Reactive Power flow to gridwithcontrollerwith change in load at 2.5sec.

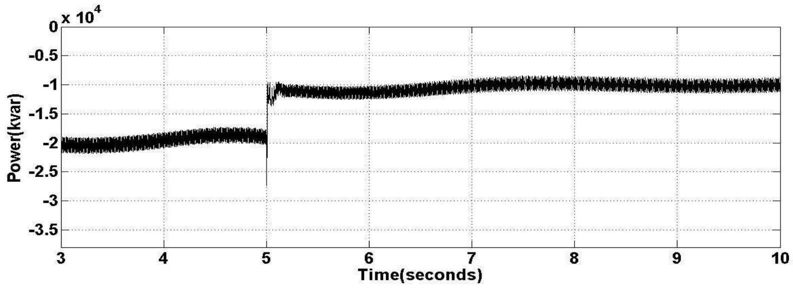

Figure 11: Reactive Power Flow, Change in Load at 2.5sec

- Voltage magnitude regain aftersudden change in load at 5 seconds. This plots clearsthatwithsudden change in loadreactive power requirementishappensowith the help of controller the reactive power requirementisovercomethatcanbeseenwith the regain of the voltage magnitude.

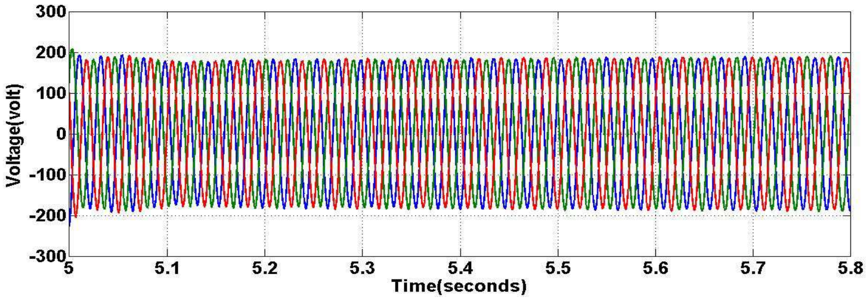

Figure 12: Inverter Output Voltage with Voltage Regain at t=5sec

CONCLUSIONS

Steady state analysis of dynamic frequency and grid support controller for grid tied power conversion system. Multilevel interleaved DC-DC boost converter is used as a DC-link and Voltage source inverter is simulated to interface DG with Grid and to control the power flow to the grid. A dynamic frequency controller is designed to control phase angle of static converter with respect to frequency changes to handle sudden changes in energy demand and implemented along with a grid supporting active and reactive power control of VSI in Matlab/Simulink. Simulation is done with sudden change in load, respective results are plotted and effectiveness of the controller is clearly seen in the results.

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